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REPORT NO. 87-26

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BETHESDA, MARYLAND

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LIFTING AND CARRYING CAPACITIES RELATIVE TO PHYSICAL FITNESS MEASURES *

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*Report Number 87-26, supported by the Naval Medical Research and Development Command, Bethesda, Maryland, Department of the Navy, under research Work Unit No. 63706N M0096.02-1050. The opinions expressed in this paper are those of the authors and do not reflect official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government.

ACKNOWLEDGEMENTS

Sincere gratitude and appreciation are extended to the co-workers who helped us perform this study. Petty officers Jennifer Hiett, Kevin Kauers, Kirk Buker, Lee Barr, Tracye Miner and Fred Harris, as well as, Ann-Marie Butler, LTJG Doug Lambert and ENS Joe Labco provided invaluable assistance during the planning, implementation and data analysis phases of this research project. Their diligence, competency and enthusiasm assured consistent high-quality data collection. The participants of this study also deserve a special thanks. Their motivation, persistence, and good nature in the face of demanding tasks were indispensable to the success of this project.

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SUMMARY

Through the Physical Readiness Test (PRT), the Navy assesses the physical fitness and body composition of its members. Those fitness attributes which contribute to optimal Navy job performance have not yet been fully identified. The purpose of this study was to determine the extent to which performance of simulated general shipboard work can be predicted by measures of physical capacity.

Three tasks representative of general shipboard work were developed - a long duration carry and two maximal box lifting tests. These tasks, as well as, PRT items (including lean body mass [LBM] from body circumferences and weight), other field fitness measures, and Incremental Lift Machine (ILM) tests were performed by 102 Navy men and women.

Multiple regression results show that PRT scores can be used to predict performance of carry and lift tasks representative of general shipboard work. Run time and LBM predict carry task performance ($R = .72$, S.E. = 28.7 watt), while LBM and push-up score predict box lifting capacity ($R = .81$ to $.88$, S.E. = 7.6 to 13.2 kg). These predictions are age- and gender-free.

Substitution of broad jump score for LBM offers a small improvement in task prediction. ILM scores offer lift capacity prediction comparable to that obtained from PRT and broad jump scores.

LBM, broad jump and ILM scores are all strong indicators of overall body strength.

If these prediction methods are to be implemented as screening or selection tools, critical lifting and carrying task parameters for Navy jobs must be defined. In addition, further research is needed to cross-validate results obtained in this study and to expand prediction application.

1. INTRODUCTION

Physical fitness measurement provides an indication of the ability to perform physical work (Knuttgen, 1977; Hodgdon, 1986). NIOSH (1981) finds that the maximal weight which can be lifted is related to muscle strength. The studies of Petrofsky and Lind (1978) and Monod (1985) suggest that work rates which can be sustained are best expressed as a percentage of physical capacity. Thus, the individual with greater physical capacity can sustain a higher work rate than the individual with a lesser physical capacity.

The Armed Services use physical fitness measures as indicators of readiness for duty, and employ physical fitness testing of Service personnel on a recurring basis to assess readiness (United States Marine Corps, 1980; Department of Defense, 1981). Recently, the Air Force and the Army have begun physical fitness testing at the Military Entrance Processing Stations (MEPS), for the purpose of physical selection for job assignment. The assessment consists of determination of the maximal weight which can be lifted to a specified height on a dynamic lift device, the Incremental Lift Machine, or ILM (McDaniel et al., 1980).

In 1982, the Navy promulgated OPNAVINST 6110.1B containing the Navy's physical readiness program. The instruction included a physical readiness test (PRT) consisting of body composition assessment and measurement of sit and reach distance, number of sit-ups which can be performed in 2 minutes, and time for a 1.5-mile run.

This study was prompted by the Navy's need to update the physical readiness instruction. One of the changes under consideration was the addition of push-ups performed in a fixed time as a test item. The Navy desired to provide performance standards for the PRT which relate to job performance demands. Although some research has been conducted in this area, those fitness attributes which determine optimal Navy job performance have not been fully elucidated.

Robertson and Trent (1985) measured the performance of Navy men and women on 16 to 34 physically demanding shipboard task simulations. Task performance was compared to a battery of anthropometric, strength, power, and calisthenic measures. These investigators reported arm power, static upper body strength, and body weight to be the best overall correlates (r = .38 to .82) of shipboard task performance. Examination of their tables of correlation coefficients also reveals that ILM scores and lean body mass (LBM) were significantly correlated (r = .36 to .67) with task performance. Correlations between task scores and push-up or sit-up scores were generally weak or nonsignificant.

Marcinik, Lawlor, Hodgdon, Englund and Trent (1987) assessed male Navy recruit performance of five simulated shipboard tasks, of PRT items, and on the ILM. Results showed significant correlations (r = .16 to .72) between task performance and most of the other test items. ILM scores and LBM, however, were the best overall correlates (r = .32 to .72) of task performance. Multiple regression analyses revealed ILM score, LBM, 1.5-mile run time, sit-up score, and % body fat to be significant predictors of task performance.

In both of these previous investigations, simulated tasks were of short duration, usually less than 30 seconds. Maximal physical exertion over a short period of time should draw upon strength and anaerobic power capacities. On the other hand, tasks of longer duration (5 minutes or more), should tax cardiovascular (aerobic) and muscle endurance capacities. Robertson's survey data (personal communication, 1982) indicates that carry tasks, often repeated and with durations of several minutes, comprise a large portion of shipboard tasks. There is a need to determine which fitness attributes are most strongly related to performance of a relatively long duration carry task.

In the previous investigations, performance was assessed on two lift-only tasks - a barbell lift to a rack, and a canopy raising simulation. Neither study examined the relationship between push-up and lift task performance. Lifting tasks comprise 20% of physically demanding shipboard tasks and involve a wide variety of objects and loads (Robertson & Trent, 1985). There is a need to determine the relationship between PRT items (including push-up) and lifting capacity during generic lifting tasks.

The purpose of this study is two-fold: 1) Determine the extent to which performance on the PRT items and other field measures predict performance of a long duration carry task and two generic lift tasks to different heights; and 2) Compare the efficacy of the ILM and other field measures of fitness in the prediction of task performance.

2. METHODS

2.1 Subjects

One hundred and two active-duty Naval personnel (64 men and 38 women), aged 20 to 35 years participated in this study. Each subject was briefed upon the nature of the study, attendant risks and benefits, and gave voluntary consent prior to testing. In addition, each participant was screened for medical conditions which could limit physical performance or increase risk of injury during testing. As a further safety precaution, prospective participants underwent an isometric, lifting-strength screening test.

During this screening test, the participant stood upright and pulled upward on the handles of a small metal box held at knuckle height. The box was attached to a dynamometer (model TCG-500, John Chatillon & sons, New York, NY) which measured maximal force generated.

The work of Monod (1985) indicates that, for intermittent static work, such as that performed in the carry task used in this study, the maximal safe load for a 10-minute performance with muscle contractions maintained 50% of the time is 45% of an individual's maximal voluntary contraction. Box weight during the carry task was 34 kg. Therefore, any participant who could not achieve an isometric lifting-strength score of at least 76 kg was precluded from further participation. Inadequate performance on this test precluded four women and no men from participating in this study.

2.2 Testing Sequence

Testing for each subject was completed within a 2-week period. Subjects visited the laboratory on four separate days (none consecutive) for the following tests: Visit 1) seven field measures of physical capacity; Visit 2) 1.5-mile timed run and lifting capacity on the ILM; Visit 3) body composition assessment and carry task; and Visit 4) box lifting capacity.

2.3 Field Measures of Physical Capacity

Three of the field tests (sit-reach, 2-minute sit-ups, and 1.5-mile run) were selected because they are part of the Navy's PRT. In addition, 1-minute push-ups, vertical jump, pull-ups, broad jump, and 100-m sprint were measured. Prior to each test, participants received a thorough briefing on objectives and proper technique, and practiced until correct form was demonstrated.

Sit-Reach. Prior to this flexibility test, participants were given time to stretch their legs and backs. The sit-reach test as described in the PRT was modified in order to quantify performance. The subject sat on the deck with knees extended, feet 15 cm apart, and soles flush against a vertical board. A horizontal scale was set at toe level and reach length beyond or short of toes was measured. Subjects reached toward/past toes as far as they could in 3 slow, progressive attempts. The last reach was held for 1 sec and recorded to the nearest 0.5 cm.

Sit-Up. Sit-ups were performed as described in the Navy's PRT instruction with feet held, knees bent, and arms crossed on chest. Correct range of motion was from shoulder blade touching deck to arm touching thigh. Rest was allowed in any position. Maximum number completed in 2 min was recorded.

1.5-Mile Run. The 1.5-mile run took place on a measured, level asphalt track. After a quarter mile walk/jog warm-up and brief rest, subjects ran in a group (2 to 10 persons). Elapsed time was announced each quarter mile and completion time was measured to the nearest 0.1 sec.

Push-Up. Push-ups were performed with the body in a "straight" line from head to heels. From the up-position, with hands approximately shoulder width apart and elbows extended, the participant bent arms until the upper chest (manubrium) touched a fist (8-10 cm in height) on the deck and then extended arms to return to the up-position. Rest was allowed at any time and in any body position, and maximum number of push-ups completed in 1 min was recorded.

Vertical Jump. To perform the vertical jump, the participant stood with right side to a wall, feet parallel and a comfortable distance apart. He/she then crouched while swinging arms backward, and jumped vertically trying to reach a marker directly overhead and high on the wall.

Jump distance was measured with an apparatus and procedure similar to that described by Bertina and van Dijk (personal communication, 1986) for testing of Dutch Army recruits. The participant stood on a sheet of wood (100 x 108 cm) which contained a tape measure passing through two wire staples. One end of the tape measure was attached to the lower edge of the participant's shorts. The other end of the tape was read (to nearest 0.1 cm) at the point where it passed through one of the wire staples before and after each of three jumps. The largest difference between pairs of readings was designated the final score (VJUMP).

Pull-Up. During the pull-up, an overhead bar was grasped with palms facing body and body suspended above deck. Only pull-ups that started at full elbow extension and ended with the larynx (adam's apple) reaching or clearing the bar were counted. No kicking or swinging of legs was allowed. Pull-ups were done in a continuous manner (a pause of 1 sec or longer terminated test) and maximum number completed was recorded.

Broad Jump. The broad jump was performed on a concrete surface. Participants placed toes behind starting line and jumped forward to cover as much horizontal distance as possible. Jump distance was measured from starting line to body part touching deck closest to starting line (to nearest 0.5 in. [1.3 cm]). The longest of three trials was used as the final score (BJUMP).

100-m Sprint. A 100-m sprint was run from a standing start on a measured, level asphalt surface. After a brief warm-up, subjects ran in pairs and sprint time was recorded to the nearest 0.1 second.

2.4 Incremental Lift Machine (ILM)

The ILM consists of an adjustable weight stack (18.14 to 90.72 kg in 4.54 kg increments), a lift bar, and two upright tracks that guide the weights during a lift. Lift bar handles are 3 cm in diameter and allow for a grip width of 40 to 60 cm. These handles rest 28 cm above the deck and can be raised to a height of 211 cm. For our purposes, a tape measure was attached to one of the uprights so that bar height during lifts could be monitored. In this study, three ILM tests were administered: 1) a lift and curl to elbow height; 2) a lift and press to 152 cm; and 3) an endurance hold. Prior to each test, proper technique was explained and demonstrated, and the subject practiced (with low resistance) until correct form was achieved. If a participant used unsafe techniques (e.g., forward flexion of the spine or extending the knees while bent forward at the hip) during practice or testing, the lift was terminated immediately and corrective instructions given.

<u>ILM Lift and Curl to Elbow Height.</u> As the subject stood with feet shoulder width apart, arms bent to 90 degrees and forearms parallel to the deck, elbow height was assessed and marked on the tape measure attached to the ILM upright. During the lift, the bar was grasped with palms facing away from the body, and a straight-back, bent-knee lift followed by arm flexion to 90 degrees was used to raise the bar to the elbow height marker (Figure 1). Unsafe form, arching the back, lifting the heels off the deck (except during take-off), or discontinuous bar motion disqualified a lift attempt.

After 3 warm-up repetitions at a resistance approximately equal to 25% of body weight, the subject alternated 1-min rest periods with single lift attempts. Resistance for the first maximal lift attempt was approximately 50% of body weight. After a successful lift, resistance was increased in increments conducive to achieving a maximal lift within 2 to 3 attempts. After an unsuccessful attempt, resistance was decreased in 4.54 kg increments until a maximal lift score was identified. If the entire ILM weight stack (90.72 kg) was lifted successfully, bags of lead shot (in multiples of 4.54 kg) were added to the weight stack for subsequent attempts. Final score (ILMCURL) was the largest resistance lifted successfully.

Figure 1. Ending position for ILM lift and curl to elbow height (ILMCURL).

Figure 2. Ending position for ILM lift and press to 152 cm (ILMPRES).

ILM Lift and Press to 152 cm. After completion of ILMCURL, subjects rested for 5 min while procedures for the second ILM test were explained and demonstrated. To perform this lift, the lift bar was grasped with palms facing toward the body, and a straight-back, bent-knee lift followed by partial arm extension was used to raise the bar to a 152.4 cm marker on the apparatus (Figure 2). During the arm-extension phase of the lift, movement at the knee joint was not allowed. A lift was also disqualified if the subject used unsafe technique, or paused longer than 1 sec during any portion of the lift. Warm-up lifts, rest periods, and attempts at progressively increasing resistance were performed in same manner as for the ILMCURL test. Final score (ILMPRES) was the largest resistance lifted successfully.

ILM Endurance Hold. The third ILM test was designed to measure holding endurance. Resistance was set to one-half of ILMCURL. The subject raised the ILM bar to his elbow height, using ILMCURL technique, and held it there as long as possible. Time was measured from the instant the bar was placed at elbow height to the moment the bar fell more than 3 cm. Arching the back or lifting the heels off the deck terminated the test. Holding time to the nearest second was recorded as the final score (ILMHOLD).

2.5 Body Composition

Percent body fat (%FAT) was assessed via body circumference measures and height according to procedures and regression equations described by Hodgdon and Beckett (1984a, 1984b). The Navy's current PRT instruction, OPNAVINST 6110.1C, uses the same measurements and equations for %FAT determination.

Participants were weighed in minimal clothing (men in shorts, women in shorts and t-shirt) to the nearest 0.05 kg on a calibrated load cell platform interfaced with a digital indicator (Model WS2000, Western Scale Co., San Diego, CA). Height was measured to the nearest 0.1 cm using a wall-mounted, retractable tape measure with Broca plane attached (KaWe, West Germany). Subjects were barefoot, stood with heels together, took a deep breath, and "stretched tall" while the Broca plane was placed on the vertex of the head and the measurement taken.

Neck and abdomen (for men) or neck, waist, and hip (for women) circumferences were each measured (to the nearest 0.1 cm) twice. A third measurement was taken if the first two trials differed by 1 cm or more, and the average of all trials at a site was taken as the final score. Circumference measures and height were entered into the regression equations and %FAT was calculated to the nearest 0.1%.

2.6 Box Carry Task

Robertson and Trent (1985) reported that carry-while-walking tasks comprise the largest category (48%) of physically demanding shipboard tasks. In order to develop the box carry task used in the present study, raw survey/interview data (personal communication from Robertson, 1982) describing physically demanding shipboard tasks were analyzed. Procedures by which these data were collected are reported by Robertson and Trent (1985). Results of our analyses were used to create a carrying task representative of commonly occurring shipboard work. We have subsequently obtained and analyzed additional raw data collected by the same investigator. We now have descriptions of 47 carry or lift-carry tasks for nine shipboard rates. This additional data has altered the summary statistics which were the basis for carry task design, however, box carry task parameters are still quite similar to those of the surveyed shipboard tasks. Table 1 compares shipboard task parameters with those of the box carry task used in this study. Because of the non-normal distribution of shipboard task survey data, median statistics were chosen as the best descriptors of task parameters. It should be noted that many shipboard carry tasks involved some ladder travel, but for safety reasons we did not incorporate ladders into the box carry task. A full summary of the Robertson survey data is provided in Appendix A.

Table 1. Comparison of carry and lift-carry shipboard task (N=47) parameters with those of the box carry task used in this study.

Parameter	Shipboard Tasks*	Box Carry Task
Object	most common-gas cylinder, bucket, valve	small metal box with handles
Object weight (kg)	36.3	34.0
Carry segment distance (m)	30.5	51.4
Total task time (min)	12.5	11.0
Rests per task (#)	1.0	1.0

* Median Statistics

In the box carry task, participants carried a small metal box (33L X 25W X 20H cm) with solid bar handles (46 cm apart). This particular object was selected for this task because it 1) allowed variable weight loading; 2) was shaped for safe and convenient handling; and 3) was easily obtainable since it was built for the lifting tasks described later in this report.

The height of the platform holding the box to be carried was adjusted before the task began. The platform was adjusted to be even with the base of the box when the subject held it against the thighs, with arms fully extended and feet shoulder width apart (Figure 3a). This height was selected to minimize any lifting of the box during the ensuing task. The box was loaded to 34 kg. The objective of the task was to make as many round trips as possible on a 51.4-m course in two 5-minute bouts with 1 min rest between bouts. Each trip started from the platform. Alternate trips, beginning with the first, were made with the box. Figure 3 depicts several phases of the box carry task. Subjects were instructed to carry the box in the most comfortable position, but it had to be carried by the handles and in front of the body. Running was not allowed, but participants were instructed to walk as fast as possible both with and without the box. Verbal encouragement was given by test monitors throughout the task.

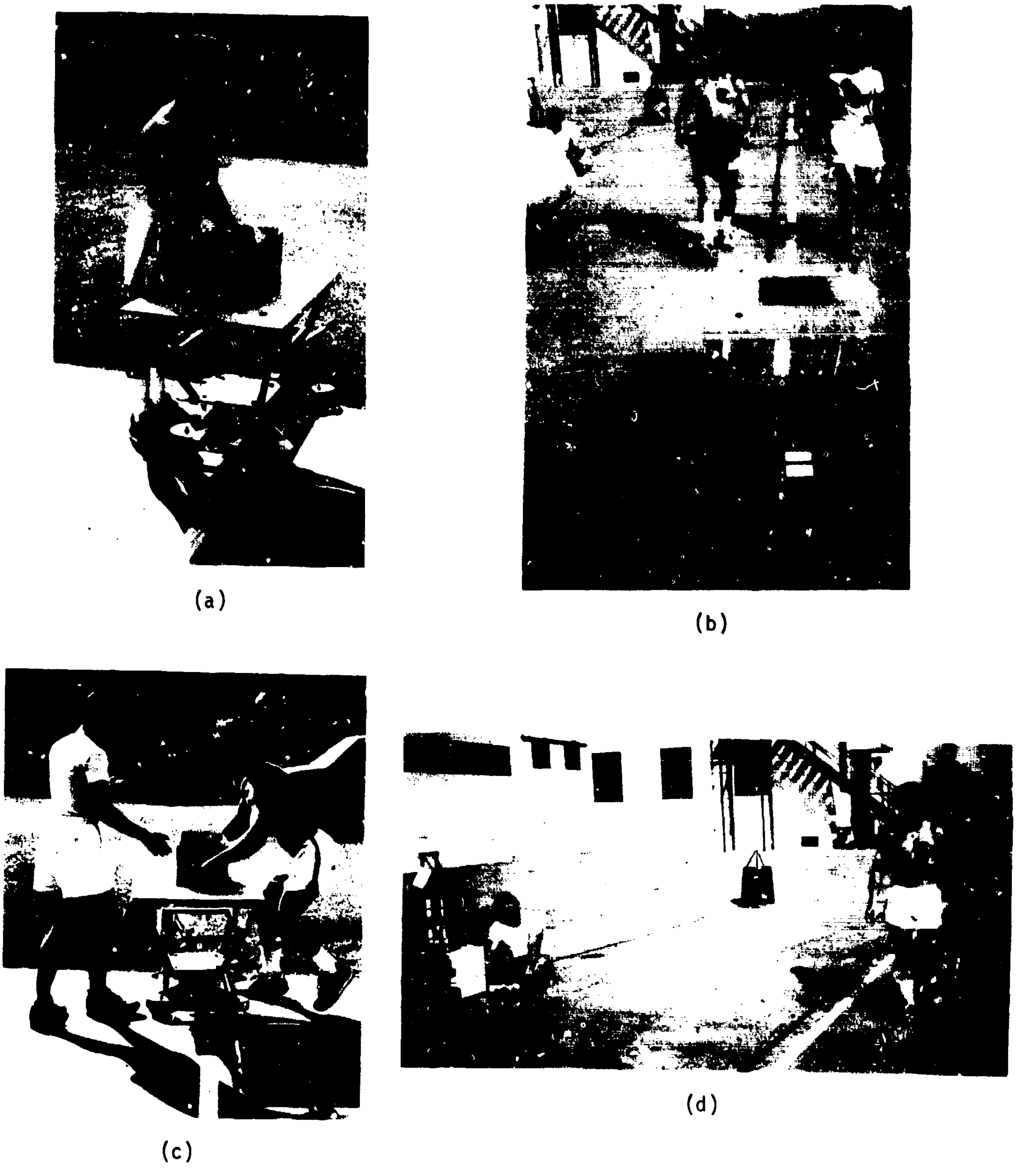

Figure 3. Box Carry Task: a) platform adjusted to knuckle height, subject ready to begin; b) lap while carrying box; c) replacing box upon platform; d) lap without box.

Elapsed time was announced and recorded at the end of each round trip. For each 5-min bout, number of round trips completed and distance of partial trip (at end of bout) was recorded.

2.7 Box Lifting Capacity

Robertson and Trent (1985) reported that lifting tasks make up the second largest category (20%) of physically demanding shipboard duties. Many different objects are lifted or lifted-carried, but the most common are pump casings, valves, chocks, cored metal billets, and 4-jaw chucks. This variety of objects, together with safety and practical (e.g., variable weight loading) aspects were considered during selection of an object for this study's lifting capacity tests. During their studies of repetitive lifting capability, Legg and Pateman (1985) used a small metal pallet with handles and strict squat technique when they assessed lifting capacity of British soldiers. Because Legg reported (personal communication, 1985) no injuries during his lifting tests, the object and procedures he used were adapted to meet the needs of the present study.

A rectangular metal box (Figure 4), 33L X 25W X 20H cm, was constructed. Solid bar handles (20L X 3.3D cm) at each end were 46 cm apart and 9 cm above box base. Two lifting tests were administered in sequence. In the first test, the box was lifted from deck to elbow height, while in the second test, the box was lifted from deck to knuckle height. In each test, an adjustable platform (Figure 4) was set to the appropriate height and the subject was required to place the box on the platform. Prior to each test, proper lifting technique was explained and demonstrated, and the subject practiced with an empty box (5.67 kg) until correct form was achieved. If unsafe lifting technique was used during practice or testing, the lift was terminated immediately and corrective instruction given.

Box Lift to Elbow Height. In order to obtain the proper platform height for the box lift to elbow height test, the subject stood with feet shoulder width apart, held the box with arms flexed to 90 degrees, and the platform was set even with the base of the box. This lift test required a knees-bent, straight-back, bimanual lift from the deck (Figure 5) followed by 90-degree elbow flexion to place the box on the platform (Figure 6). No

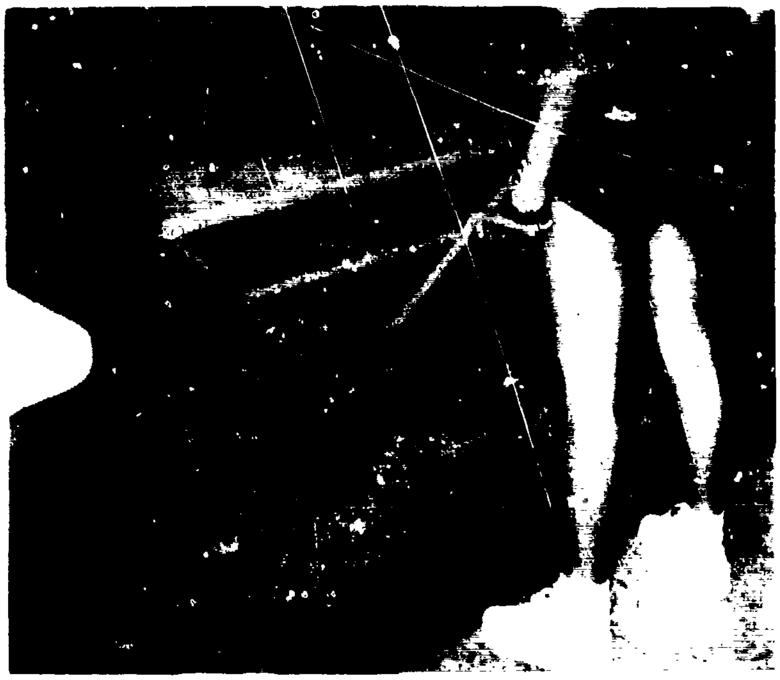

Figure 4. Maximal box lift testing apparatus: adjustable-height platform and loaded metal box.

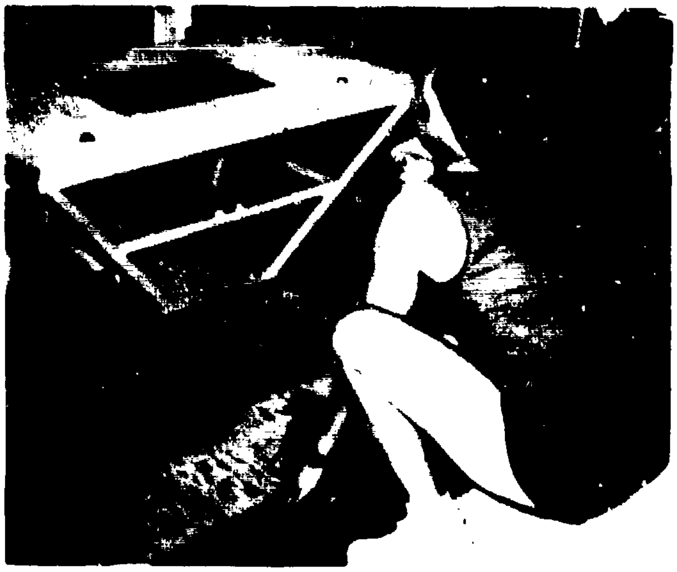

Figure 5. Starting position for box lift. This knees-bent, straight-back technique was used during both lift tests. In this photo, platform is set for a lift to knuckle height (BXKNCL).

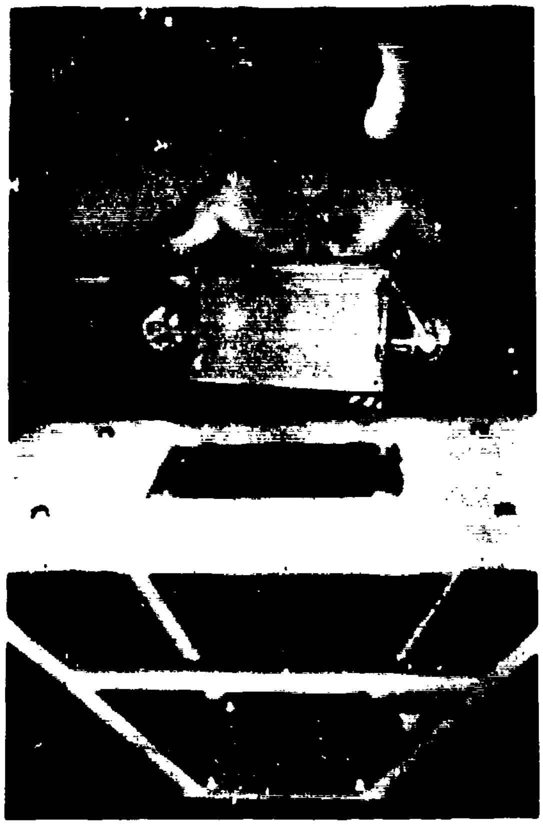

Figure 6. Box is placed upon platform at end of a box lift to elbow height (BXELBO) trial.

standing on tip-toes or arching of back was allowed during placement of box on platform. To begin the test, the box was loaded with unmarked bags of lead shot, to approximately 30% of the participant's body weight and 5 warm-up lifts were performed. A 1-minute rest period was given at that time and between all subsequent trials. The next attempt was made with the box loaded to approximately 60% body weight. Following each successful lift, box weight was increased by 11.34 kg for the next attempt. After the first unsuccessful attempt, box weight was decreased to the last successful lift plus 4.54 kg and another attempt made. Box load was then increased by 4.54 kg each attempt until another unsuccessful lift. At that point, load was decreased by 2.27 kg and a final attempt made. In this manner, capacity for lifting to elbow height (BXELBO) was determined to the nearest 2.27 kg.

Box Lift to Knuckle Height. After 5 min of rest and a review of technique, the second lifting test began. During this test, the box was lifted from the deck to a platform set at knuckle height (Figure 5). The platform was adjusted to be even with the base of the box when the subject held it against his/her thighs, with arms fully extended and feet shoulder width apart. Lift technique was the same as that used in the initial phase of the BXELBO technique. Box weight for the first lift attempt was BXELBO score plus 11.34 kg. A 1-minute rest was taken between all trials. After each successful lift, box weight was increased by 11.34, 22.68, or 34.02 kg at the discretion of the test operator, whose objective was to reach the maximum lift in the least number of repetitions. Box weight adjustment after the first unsuccessful attempt was the same as that described for the first lifting test. In this manner, capacity for lifting to knuckle height (BXKNCL) was determined to the nearest 2.27 kg. The heaviest load the box could accomodate was 113.40 kg. If a participant achieved this maximum load, it was designated as the final score.

2.8 Statistical Methods

During preliminary data analysis, the following score transformations were performed:

Lean Body Mass. Lean body mass (LBM) was derived from body weight and %FAT. The purpose of this transformation was to create a PRT score reflective of muscle mass and strength.

LBM (kg) = body weight (kg) - [(%FAT/100) X body weight (kg)]

Work Indexes. Work indexes were computed for pull-up (PULLUPWK), vertical jump (VJUMPWK), and broad jump (BJUMPWK) by multiplication of raw scores (number of pull-ups or jump distance) by body weight (kg). Work indexes in kgm units were converted to joules (1 joule = .102 kgm).

ILM Impulse. ILM impulse (ILMIMP) was calculated from ILM holding endurance score as the product of weight held and endurance time.

ILMIMP = weight held (kg) X ILMHOLD (sec)

Box Carry Power. Box carry task performance was expressed in units of power. Distance the box was carried for each 5-min bout was computed and summed to yield the total carry distance for the entire task. Time for each bout was calculated as the time from the beginning of the bout to the end of the last box carrying trip. Task time was computed as the sum of the two bout times plus 1 min (rest period between bouts). Box carry power (BCPWR) was then computed as follows:

BCPWR (kgm/sec) = [box wt (kg) X distance carried (m)] / time (sec)
BCPWR (watt) = BCPWR (kgm/sec) / [.102 (kgm/sec)/watt]

Statistical analyses were performed on a VAX 11/780 computer using SPSSX (SPSS Inc., 1986). For all test statistics, significance was accepted when $p < .05$. The T-Test procedure was used to test for differences between the women and men. The Pearson Correlation procedure was used to produce a cross-correlation matrix for all variables. Selected pairs of correlation coefficients were tested for differences according to the method of Cohen and Cohen (1975) using the "t" statistic. This method allows determination of the significance of a difference between correlations of two measures with a third.

Multiple regression (SPSSX Regression procedure) was used to develop regression equations for predicting box carry and lift scores from subsets of PRT scores, field test scores, and ILM measures. Five multiple regression models (Table 2) were tested for each of the three criterion variables (BCPVR, BXELBO, BXKNCL). During multiple regression, independent (predictor) variables were allowed to enter in a stepwise fashion as long as the resultant change in accounted-for variance was at least 3%.

Table 2. Multiple regression models for prediction of each of the criterion variables - BCPVR, BXELBO, and BXKNCL.

Model	Variables Allowed to Enter
	Age and gender plus:
1	PRT scores (LBM, push-up, sit-reach, sit-up, 1.5-mile run)
2	PRT scores, other field measures: 100-m sprint, pull-up, broad jump, vertical jump
3	PRT scores, 100-m sprint, work indexes for pull-up, broad and vertical jumps
4	ILM scores (ILMCURL, ILMPRES, ILMHOLD, ILMIMP)
5	ILM scores, best predictors resulting from Model 1 analysis

Regression equations resulting from these analyses were used to compute predicted scores for the criterion measures. Standard errors of the estimate (S.E.) were expressed both in the units of the criterion variable and as a percent of the mean criterion score.

3. RESULTS

3.1 Descriptive Statistics

Participant characteristics and physical performance scores are presented in Table 3. Women and men differed significantly in all variables except age and sit-up. In general, the men had greater body size, less %FAT, more LBM, and higher physical performance scores than the women. For

Table 3. Participant Characteristics and Performance Scores (N = 64 men & 38 women)*

Variable	Men Mean	Men S.D.	Men Range	Women Mean	Women S.D.	Women Range
AGE (yr)	27.8	[illegible].93	20-35	27.6	4.14	21-35
HEIGHT (cm)	177.8	7.0[illegible]	157.5-192.0	165.4	6.02	154.0-178.0
WEIGHT (kg)	81.5	12.17	54.7-112.6	61.4	7.64	49.6-81.3
BODY FAT (%)	18.0	6.91	3.5-31.5	26.3	4.86	16.5-36.4
LBM (kg)	66.2	6.81	47.8-79.4	45.0	3.75	37.1-54.3
BCPWR (watt)	304.8	38.99	212.5-397.9	271.4	37.20	211.4-383.0
BROAD JUMP (m)	2.138	.233	1.346-2.756	1.735	.186	1.372-2.070
BJUMPWK (joule)	1719.7	289.95	1123.3-2356.6	1050.6	161.24	795.1-1396.8
BXELBO (kg)	65.8	11.94	40.8-90.7	40.2	6.85	25.0-56.7
BXKNCL (kg)	93.2	17.64	49.9-113.4	60.3	13.41	31.8-90.7
ILMCURL (kg)	66.9	15.55	40.8-117.9	35.9	6.18	27.2-45.4
ILMHOLD (sec)	40.3	16.75	2-80	51.9	19.52	20-129
ILMIMP (kg X sec)	1308.5	550.80	117.9-2903.0	924.9	363.71	362.9-2340.6
ILMPRES (kg)	61.6	13.38	31.8-99.8	32.3	5.40	22.7-49.9
PULLUP (#)	8.2	5.64	0-22	1.0	2.10	0-10
PULLUP WORK (# X kg)	647.0	431.05	0-1768.3	57.7	14.58	0-520.7
PUSHUP (# in 1 min)	35.0	15.98	8-87	13.1	9.74	0-42
SIT-REACH (cm)	8.9	7.65	-7.5-25.5	14.3	7.93	-9.5-26.0
SITUP (# in 2 min)	58.5	19.19	28-122	60.9	20.40	19-117

Table 3. (Continued)

	Men			Women		
Variable	Mean	S.D.	Range	Mean	S.D.	Range
VERTICAL JUMP (m)	.501	.080	.334-.664	.401	.051	.290-.510
VJUMPWK (joule)	401.1	72.71	252.2-602.2	242.0	33.60	182.3-313.3
1.5-MILE RUN (min)	11.51	2.28	8.00-19.03	13.42	2.40	9.25-19.90
100-M SPRINT (sec)	15.0	1.41	10.8-19.0	17.9	2.22	15.0-27.2

* Due to missing data, men's N = 62, 60, 61, and 63 for BCPWR, BXELBO, BXKNCL, and ILMPRES respectively

Key to Variable Names

LBM	lean body mass
BCPWR	box carry power
BJUMPWK	broad jump work index
VJUMPWK	vertical jump work index
BXELBO	maximal box lift to elbow height
BXKNCL	maximal box lift to knuckle height
ILMCURL	Incremental Lift Machine (ILM) maximal lift and curl to elbow height
ILMHOLD	time of holding 0.5(ILMCURL) at elbow height
ILMIMP	ILM impulse (ILMHOLD X 0.5[ILMCURL])
ILMPRES	ILM maximal lift and press to 152.4 cm height

all measures, however, ranges of men's and women's scores overlapped. Nearly identical score ranges were observed for men and women in age, BCPWR, sit-reach, sit-up, and 1.5-mile run time.

Means (and S.D.s) for the number of trials performed to reach maximal score during the lifting tests were 4.0 (1.8), 3.1 (1.5), 4.2 (1.3), and 4.3 (1.8) for ILMCURL, ILMPRES, BXELBO, and BXKNCL respectively. In BXKNCL, 13 men were able to lift the heaviest load (113.40 kg) the box could accommodate.

3.2 Variable Intercorrelation

The correlation matrix for all variables is presented in Table 4. Correlations between age and most other variables were nonsignificant. Age was, however, weakly but significantly correlated with BCPWR, ILMIMP, pull-up, push-up, and vertical jump scores (r = -.20 to -.23).

Height, weight and LBM were all highly intercorrelated (r = .72 to .89). Results of correlation coefficient t-test procedures indicated LBM was correlated with BCPWR, BXELBO, and BXKNCL to a significantly greater degree than was body weight (t = 4.45, 4.76, 4.04 respectively). On the other hand, there were no significant differences between LBM and ILMPRES correlations with BCPWR (t=1.39), nor with BXELBO (t=1.84). ILMPRES was, however, correlated with BXKNCL to a greater degree than was LBM (t = 2.68).

Box carry power was most strongly correlated with 1.5-mile run time (r = -.67). Box lifting capacity scores were highly correlated with ILMPRES, BJUMPWK, LBM and ILMCURL (r = .80 to .89).

Other strong correlations of note were pull-up with push-up (r = .82), BJUMPWK with VJUMPWK (r = .90), ILMCURL with ILMPRES (r = .87), and 100-m sprint with BJUMP (r = -.77).

Table 4. Pearson Correlation Coefficient Matrix

	AGE	HEIGHT	WEIGHT	%FAT	LBM	BCPWR	BJUMP	BJUMPWK	BXELBO	BXKNCL	ILMCURL
AGE	--										
HEIGHT	-.03	--									
WEIGHT	.03	.72	--								
%FAT	.18	-.39	.09	--							
LBM	-.06	.85	.89	-.38	--						
BCPWR	-.23	.41	.26	-.43	.44	--					
BROAD JUMP	-.10	.46	.37	-.61	.63	.45	--				
BJUMPWK	-.03	.73	.87	-.25	.93	.41	.77	--			
BXELBO	.00	.62	.73	-.36	.85	.54	.69	.86	--		
BXKNCL	-.03	.56	.66	-.36	.78	.53	.73	.83	.86	--	
ILMCURL	-.06	.56	.62	-.43	.78	.49	.63	.75	.79	.80	--
ILMHOLD	-.13	-.19	-.32	.01	-.30	-.04	-.17	-.30	-.23	-.22	-.38
ILMIMP	-.22	.28	.19	-.40	.37	.37	.35	.32	.46	.45	.37
ILMPRES	-.09	.66	.75	-.39	.88	.50	.69	.87	.89	.85	.87
PULLUP	-.23	.36	.15	-.77	.50	.55	.65	.45	.62	.58	.64
PULLUPWK	-.21	.43	.26	-.72	.59	.56	.69	.54	.69	.64	.69
PUSHUP	-.20	.25	.17	-.70	.48	.56	.59	.42	.63	.58	.61
SITRCH	-.07	-.35	-.35	.06	-.36	.01	-.10	-.28	-.21	-.18	-.25
SITUP	-.17	-.04	-.18	-.27	-.03	.31	.09	-.07	.00	.06	.13
VERTICAL JUMP	-.21	.28	.19	-.60	.46	.39	.77	.52	.50	.53	.55
VJUMPWK	-.12	.65	.77	-.32	.86	.42	.73	.90	.79	.77	.76
1.5-MILE RUN	.19	-.28	.01	.63	-.29	-.67	-.39	-.20	-.34	-.36	-.35
100-M SPRINT	.17	-.34	-.25	.64	-.53	-.54	-.77	-.57	-.62	-.64	-.62

Table 4. (Continued)

	ILMHOLD	ILMIMP	ILMPRES	PULLUP	PULLUPWK	PUSHUP	SITRCH	SITUP	VJUMP	VJUMPWK	1.5-MI RUN
ILMHOLD	--										
ILMIMP	.64	--									
ILMPRES	-.30	.40	--								
PULLUP	.02	.56	.63	--							
PULLUPWK	-.02	.56	.71	.98	--						
PUSHUP	-.03	.50	.61	.82	.81	--					
SITRCH	.27	.08	-.28	-.08	-.11	-.08	--				
SITUP	.04	.12	.06	.28	.26	.37	.16	--			
VERTICAL JUMP	-.14	.31	.56	.67	.68	.57	-.06	.07	--		
VJUMPWK	-.29	.32	.85	.53	.61	.48	-.27	-.07	.77	--	
1.5-MILE RUN	-.06	-.34	-.35	-.56	-.55	-.58	.04	-.51	-.43	-.28	--
100-M SPRINT	.06	-.40	-.64	-.65	-.66	-.66	.14	-.22	-.69	-.60	.61

Note: Listwise N = 97; df = 95.
Significance levels (two-tailed test): p < .05 @ r = .20 to .25
p < .01 @ r = .26 to 1.0

Key to variable names can be found in Table 3.

3.3 Box Carry Regression Models

Results of BCPWR multiple regression analyses are reported in Table 5. Approximately 52% of the variance (R^2 Change) in BCPWR can be predicted by a combination of run time and any of the following variables: LBM, BJUMPWK or ILMPRES. Run time alone accounts of 45% of the variance in BCPWR. A scatterplot for regression Model 1 is presented in Figure 7. Graphically, Models 3 and 5 would resemble Figure 7.

Table 5. Results of multiple regression to predict box carry power (BCPWR).

Allowed Variables	Predictor Variables	Multiple R	R^2 Change	B*	S.E.+
Age & Gender plus					
Model 1: PRT scores	1.5-mile run	.67	.45	-9.893	
	LBM	.72	.07	0.948	
	(constant)			357.732	28.7 [9.8%]
Model 2: PRT scores Field measures	Outcome same as for Model 1				
Model 3: PRT scores	1.5-mile run	.67	.45	-10.214	
Work indexes of	BJUMPWK	.73	.08	0.029	
field measures	(constant)			374.091	28.3 [9.7%]
Model 4: ILM scores	ILMPRES	.50	.25	0.964	
	ILMIMP	.53	.04	0.016	
	(constant)			224.361	35.2 [12.1%]
Model 5: Model 1 predictors	1.5-mile run	.67	.45	-9.440	
ILM scores	ILMPRES	.73	.08	0.697	
	(constant)			372.207	28.5 [9.8%]

Note: Units are BCPWR (watt), 1.5-mile run (min), LBM (kg), BJUMPWK (joule), ILMPRES (kg), ILMIMP (kg X sec).

* B is regression coefficient

+ Standard error of the estimate (S.E.) is expressed in watts and as a percent of mean BCPWR.

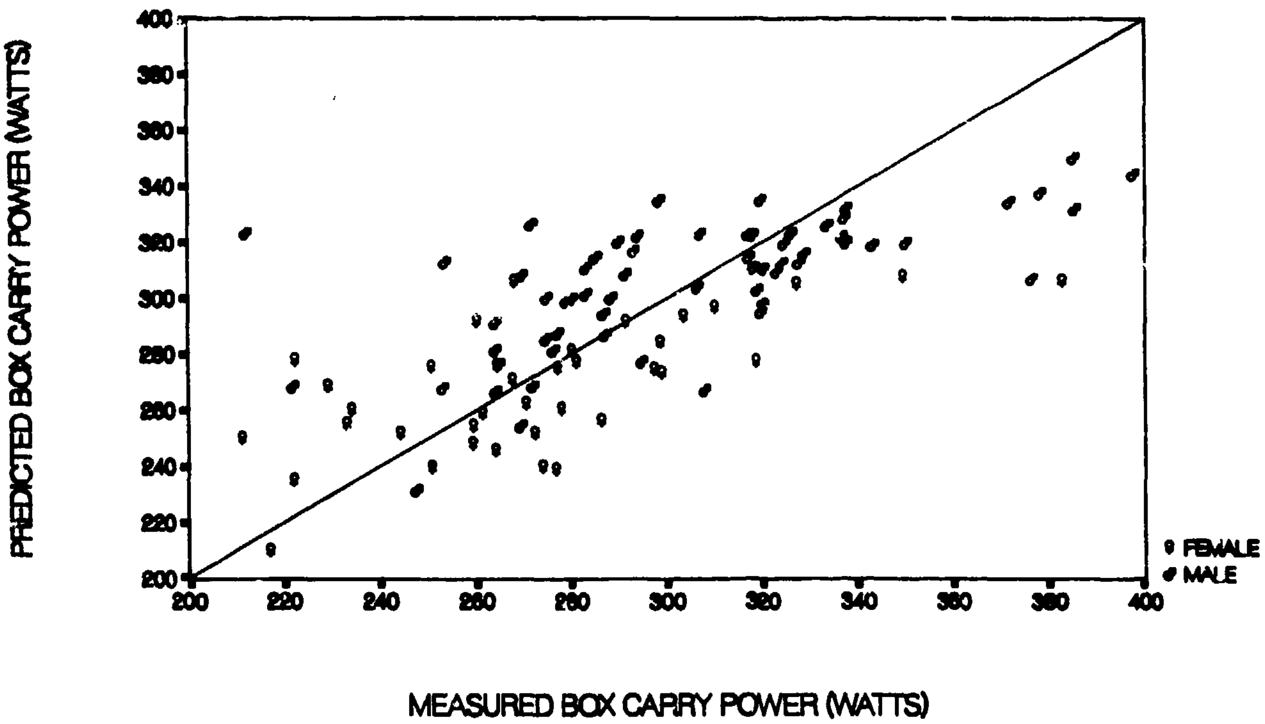

Figure 7. Measured box carry power versus its prediction from 1.5-mile run time and LBM. Line of identity is shown.

3.4 Box Lift to Elbow Height Regression Models

Predictive models for BXELBO are contained in Table 6. Of the PRT measures, LBM accounted for 71% of the variance in BXELBO, while another 6% was contributed by push-up. Figure 8 is a scatterplot of BXELBO versus its prediction by these measures. Similar predictive power is offered by the other regression models via BJUMPWK and push-up, or ILMPRES alone.

Table 6. Results of multiple regression to predict maximal box lift to elbow height (BXELBO).

Allowed Variables	Predictor Variables	Multiple R	R^2 Change	B*	S.E.+
Age & Gender plus					
Model 1: PRT scores	LBM	.85	.71	0.963	
	Push-up	.88	.06	0.267	
	(constant)			-7.506	7.6 [13.6%]
Model 2: PRT scores Field measures	Outcome same as for Model 1				
Model 3: PRT scores	BJUMPWK	.86	.74	0.029	
Work indexes of	Push-up	.91	.08	0.297	
field measures	(constant)			5.762	6.9 [12.3%]
Model 4: ILM scores	ILMPRES	.89	.79	0.800	
	(constant)			15.412	7.4 [13.2%]
Model 5: Model 1 predictors ILM scores	Outcome same as for Model 4				

Note: Units are BXELBO (kg), LBM (kg), Push-up (# in 1 min), BJUMPWK (joule), ILMPRES (kg).

* B is regression coefficient

+ Standard error of the estimate (S.E.) is expressed in kg and as a percent of mean BXELBO.

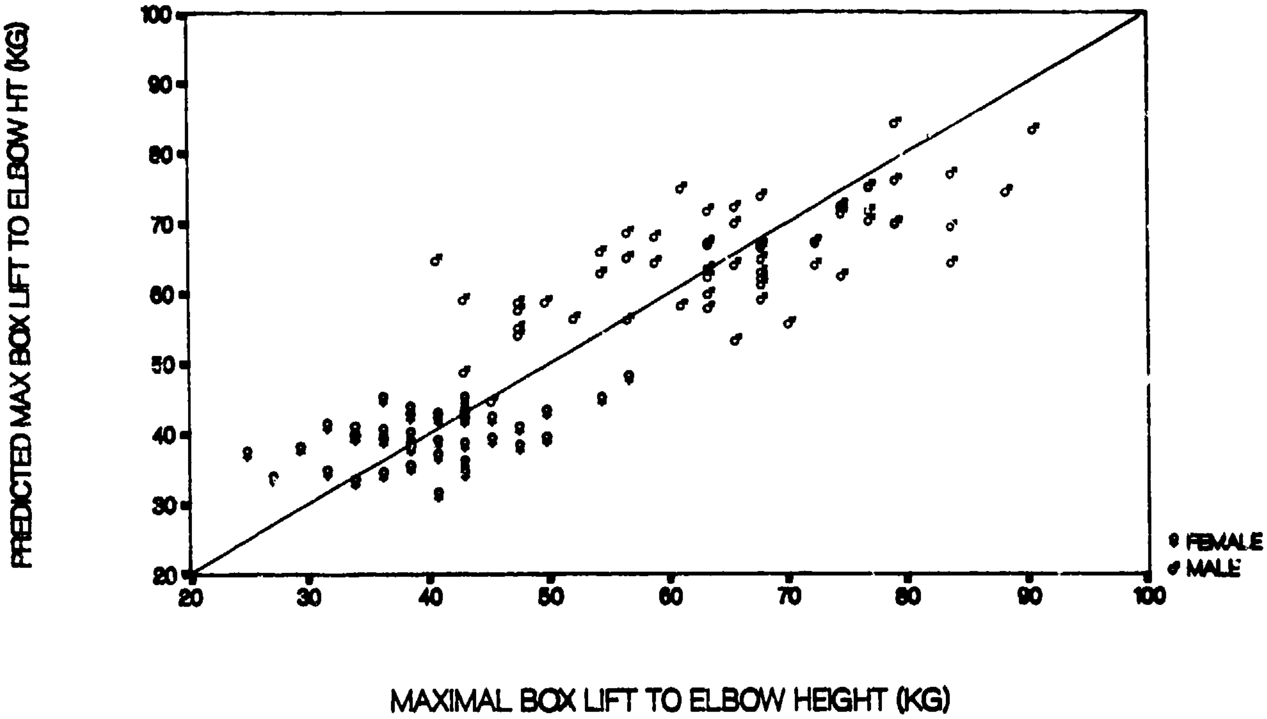

Figure 8. Measured maximal box lift to elbow height versus its prediction from LBM and push-up score. Line of identity is shown.

3.5 Box Lift to Knuckle Height Regression Models

Regression analysis results for BXKNCL are given in Table 7. Of the PRT measures, LBM and push-up accounted for 61% and 6% of the variance in BXKNCL respectively. A scatterplot of this BXKNCL regression model is presented in Figure 9. The other regression models acccunt for up to 75% of the variance in BXKNCL via these variable combinations: LBM and BJUMP, BJUMPWK and push-up, or ILMPRES alone.

Table 7. Results of multiple regression to predict maximal box li^r to knuckle height (BXKNCL).

Allowed Variables	Predictor Variables	Multiple R	R^2 Change	B*	S.E.+
Age & Gender plus					
Model 1: PRT scores	LBM	.78	.61	1.245	
	Push-up	.81	.06	0.349	
	(constant)			-1.430	13.2 [16.4%]
Model 2: PRT scores	LBM	.78	.61	1.021	
Field measures	BJUMP	.84	.09	30.585	
	(constant)			-39.772	12.4 [15.4%]
Model 3: PRT scores	BJUMPWK	.83	.69	0.039	
Work indexes of	Push-up	.86	.06	0.364	
field measures	(constant)			12.885	11.5 [14.3%]
Model 4: ILM scores	ILMPRES	.85	.72	1.073	
	(constant)			26.297	11.9 [14.8%]
Model 5: Model I predictors ILM scores	Outcome same as for Model 4				

Note: Units are BXKNCL (kg), LBM (kg), Push-up (# in 1 min), BJUMPWK (joule), ILMPRES (kg).

* B is regression coefficient

\+ Standard error of the estimate (S.E.) is expressed in kg and as a percent of mean BXKNCL.

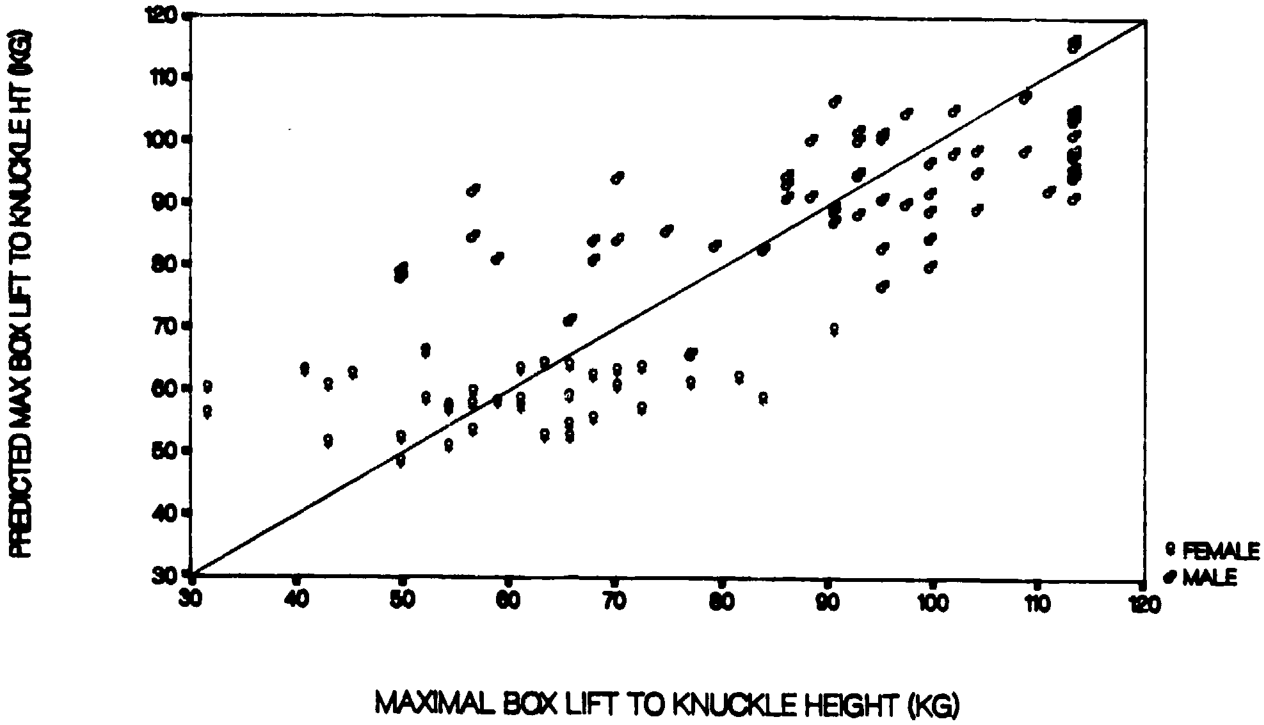

Figure 9. Measured maximal box lift to knuckle height versus its prediction from LBM and push-up score. Line of identity is shown.

4. DISCUSSION

4.1 Sample Characteristics

In the evaluation of these results, it must be borne in mind that this sample represents people who have been selected on the basis of their isometric strength (e.g., they passed the safety screen). It is unclear what the effect of including people who could not pass the screen might be on these results.

The men and women who participated in this study possessed a wide range of physical attributes and capabilities. Based on the observed range of body composition and physical performance scores, members of both genders could be classified as ranging from untrained to highly physically trained. In this sense, the sample encompasses the wide range of physical attributes expected to be present in the general Navy population.

As for PRT performance, women's and men's score ranges for sit-reach, sit-up, and 1.5-mile run were similar. In terms of mean PRT scores, men and women were not different in sit-up, but the women were more flexible in the sit-reach and had slower run times. Push-up score ranges were quite different for the genders, with the men's mean score almost three times that of the women. Our results are consistent with previous literature comparing men and women, in that we found the men to be generally larger, leaner, and higher in physical capacity than the women. There was, however, considerable overlap between genders on all scores. It is likely that the men's higher physical capacity is due largely to their being larger and leaner than the women.

4.2 Intercorrelation

The age range of subjects in this study, 20 to 35 years, is typical of a large portion of active duty Naval personnel. The results of this study indicate that, for the age range studied, age is not an important determinant of body composition or physical capacity.

Although height, weight and LBM are all significantly intercorrelated, LBM is the body size characteristic most highly indicative of physical capacity. Variance in LBM accounts for 61% to 86% of the variance in lifting strength (both ILM and box) and in the jump work indexes. These findings support the use of LBM as an indicator of overall muscle strength.

The finding that box carry task performance was most highly related to running performance suggests that repeated carrying jobs primarily tax the cardiorespiratory and muscular endurance systems.

Strong relationships between box lifting and ILM scores indicate that maximal lifting strength can be assessed with a variety of lifting maneuvers. Maximal box lifting, both to elbow and knuckle heights, is also strongly related to ability to do explosive work with the legs, as represented by the broad jump work index.

Correlation analyses also suggest 1) push-up and pull-up tests measure similar aspects of physical capacity, namely muscular endurance; 2) jumping ability is comparably measured by either the broad or vertical jump test; and 3) both sprint and broad jump capacities are dependent, in part, upon some common physical attributes such as explosive leg strength or anaerobic leg power.

4.3 Task Prediction Models

4.3.1 Age and Gender Effects

Task prediction models confirm the simple correlation results in that age does not predict task performance. The models also show that gender does not determine task performance. Although the men and women differ significantly in task performance, age and gender are not important after controlling for muscle mass (via LBM) and measures of physical capacity such as run time and push-up. These findings indicate that for the age range studied, gender-free and age-free standards can be developed for the carrying and lifting tasks used in this study.

4.3.2 Box Carry Prediction

Run time contributes most to the prediction of carry task performance, with an additional, smaller part of the variance accounted for by either LBM, BJUMPWK, or ILMPRES. These findings indicate that cardiovascular (aerobic) fitness is the primary determinant of performance of a time-urgent, 11-min carry task. The secondary determinants implicate a strength component in the task. Because variables were allowed to compete within the regression analyses, results show that both BJUMPWK and ILMPRES provide a somewhat better prediction of BCPWR than does LBM. It should be recognized, however, that differences in predictive power between the models are very small and other factors, such as the availability or feasibility of field measures, may determine the optimal model for implementation.

BCPWR regression Model 1 is made up of field measures available through the current Navy PRT (OPNAVINST 6110.1C). The prediction equation for this model is:

Predicted BCPWR (watt) = -9.893 [1.5-mile run time (min)]
+0.948 [LBM (kg)]
+357.732

Using this equation, a 54 kg person with 26% body fat (40 kg LBM) and a run time of 20 min has a predicted maximal carry power of 198 watts. Another individual weighing 80 kg with 12% body fat (70 kg LBM) and run time of 8 min will have a predicted maximal carry power of 345 watts. Operationally, the way in which to use this equation would be to define the power required for a critical job (via load, distance, and time parameters) and then derive the run time-LBM combinations that predict that required power.

Mean power (horizontal carry distance X load / time) for the 47 carry and lift-carry tasks surveyed by Robertson (see Appendix A) was 69.3 watts, with a range of 2.6 to 746.1 watts. It should be noted that these power calculations do not include vertical travel (i.e., ladders). All other parameters (load, distance, duration) being equal, power output is the same regardless of whether the displacement is horizontal or vertical. Because of biomechanical considerations, however, the energy cost of an uphill task is greater than that of a task done in the horizontal plane. At this time, the extent to which ladder travel effects the energy cost of shipboard carry tasks is not known. Further study in this area is needed.

Figure 10 is a plot of power versus time for the surveyed shipboard

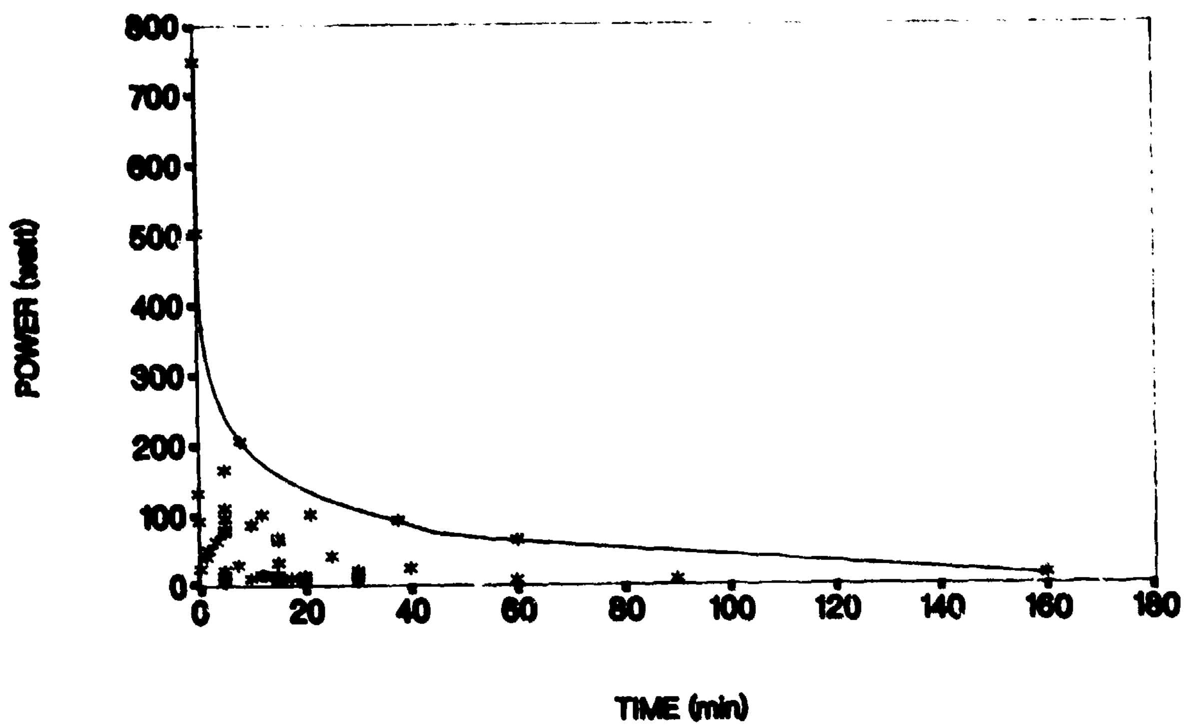

Figure 10. Power output versus task duration for physically demanding shipboard jobs. (From survey data collected by Robertson, 1982). Apparent maximum power-time envelope has been drawn.

tasks. The line drawn on this graph defines the power-time envelope within which these tasks reside. Higher power tasks are performed only for short durations, while lower power tasks are performed for longer durations. As can be seen clearly from this graph, tasks of 11 min duration would be expected to have power outputs below 200 watts. In fact, all of the surveyed tasks, except for two which had a duration of only a few seconds, involved power outputs of less than 205 watts. In the present study, mimimum and maximum power outputs for an 11-min carry task were 211.4 and 397.9 watts respectively. From these data, it is evident that most shipboard carry tasks, as defined by survey data, require power outputs well within the capabilities of subjects tested in this study. It is important to realize, however, that survey data reflect peace-time shipboard work requirements. In an emergency or war-time situation, tasks would probably be completed in less time and require higher power output. If prediction of carry performance is to be used for job selection or screening, then appropriate task time criteria must be defined.

Other factors which may limit the prediction of shipboard job performance via the results of this study are variation in carry load and duration, ladder travel, and the chaining of tasks that occurs during an entire workday. Prediction of job performance at loads and durations other than those used in this study will only be accurate if the relationship between carry power, and load and time as predictors remains the same. Further studies, with different carry loads and durations, are needed in order to examine this relationship. Many shipboard carry tasks involve ladder travel; its effect on power prediction remains to be studied. Since many tasks are performed during a single workday, prediction of single task performance may not be valid when the fatiguing effects of previous task performances exert their influence. In view of this limitation, further study of the interaction between multiple and single task performance may be warranted.

4.3.3 Box Lift to Elbow Height Prediction

Because this first lifting task required an arm curl to place the box on the platform, performance was limited by arm strength. Regression results show that this arm strength is very well predicted by field measures of fitness. The primary determinants, LBM or BJUMPWK, probably reflect overall muscle strength. The secondary determinant, push-up, may indicate a muscle endurance component in the task, or simply a close relationship between muscle strength and endurance. Results also show performance on the MEPS lifting test (ILMPRES) to be a good indicator of BXELBO. As was true with the BCPWR models, differences between the predictive power of these three BXELBO models are small.

It is important to reiterate that lifting techniques used for both maximal box lifting tests were carefully monitored and controlled so that safe and efficient lifts would be performed by all subjects. Some participants would have achieved higher scores had they been allowed to deviate from the prescribed technique. At the same time, they would have placed themselves at greater risk for injury. The maximum lifts achieved in this study reflect lifting capacity using safe and proper lifting techniques.

Lifting limits on the job, however, cannot be equated with lifting capacity. Job tasks often require repeated lifting which can generate muscle fatigue. This fatigue predisposes the worker to injury. Monod (1985) has reported that performance of dynamic work without fatigue can be achieved with the proper integration of load, distance, and task duration. Except for very short duration tasks, acceptable lifting loads are always much less than maximal. Therefore, the maximal lifts achieved in this study are not to be considered as job lifting limits. If job task parameters (such as distance and duration) are defined, however, job lifting limits could be derived from lifting capacity.

In August, 1986, the Navy issued OPNAVINST 6110.1C, a new version of the PRT instruction. At that time, data collection for the present study had been completed. The new instruction contained a 2-min push-up test, rather than the 1-min test included in this study. Since subsequent data analyses showed the 1-min push-up score to be an important predictor of box lifting capacity, the need to determine the relationship between 1-min and 2-min push-up performance became apparent. Appendix B describes our subsequent investigation of this relationship. The result was an equation for predicting 1-min push-ups from 2-min push-ups ($R = .97$; S.E. = 5.0). This equation could be used to convert Navy PRT push-up scores (2-min) to their 1-min equivalents which could then be entered into the lifting capacity prediction equations.

BXELBO prediction from Model 1 (LBM and push-up) is obtained through the following equation:

$$\text{Predicted BXELBO (kg)} = +0.963\ [\text{LBM (kg)}] \\ +0.267\ [\text{Push-up (\# in 1 min)}] \\ -7.506$$

An individual weighing 85 kg with 20% body fat will have 68 kg of LBM. If that person can do 100 push-ups, predicted BXELBO is 85 kg; if no push-ups can be done, predicted BXELBO is 58 kg. This equation can also be used in a reverse manner by defining the critical weight to be lifted and then deriving the LBM-push-up combinations meeting this criterion.

Ten lift-only (1.2 m or less horizontal displacement) tasks were reported in Robertson's 1982 survey data (personal communication). Vertical displacement ranged from 15.2 to 152.4 cm, with a mean of 88.9 cm. In BXELBO and BXKNCL tests, mean vertical displacements were 109.1 and 80.7 cm respectively. Table 8 compares men's and women's maximal box lift scores with the object weights reported for shipboard tasks. Although differences in vertical displacement make comparison difficult, some conditional interpretations can be made. If lifting to elbow height is required, all of the men and nearly all of the women in this study could succeed with the minimum shipboard object weight. If the same lift was performed with the mean object weight, 50% of men and none of the women would succeed. None of this study's participants achieved BXELBO equal to or greater than the maximum shipboard object weight. Shipboard survey data show that this maximum weight (103 kg) was lifted from the deck to a height of 96.5 cm. Since mean BXELBO lift height was 109.1 cm, it is likely that BXELBO scores underestimate the maximum weight that could be lifted to 96.5 cm. Further discussion of this table, with respect to BXKNCL, will be made in a later section of this report.

Table 8. Maximal box lift scores compared to shipboard task object weights.*

Shipboard Task (N=10) Object Weight	% Maximal Box Lift Scores Equaling or Exceeding Shipboard Task Object Weights			
	BXELBO		BXKNCL	
	Men	Women	Men	Women
Mimimum (27.2 kg)	100	97	100	100
Mean (67.6 kg)	50	0	90	29
Maxmimum (103.0 kg)	0	0	31	0

* Shipboard task data is from Robertson survey (1982).

4.3.4 Box Lift Knuckle To Height Prediction

The second lifting task did not require arm flexion, and thus performance was limited by leg and hip strength. Regression results show that this lower body strength is moderately well predicted by field measures of overall muscle strength (LBM), leg power (BJUMP and BJUMPWK), and muscle endurance (push-up). As was true in the first box lifting task, push-up explains only a small portion of the variance in BXKNCL. BXKNCL can also be predicted from performance on the MEPS lifting test (ILMPRES). Comparison of models via regression statistics suggests Model 3 (LBM and BJUMPWK) may be the best predictor of BXKNCL, although differences between models are small.

BXKNCL prediction from Model 1 (LBM and push-up) is obtained through the following equation:

$$\begin{aligned}\text{Predicted BXKNCL (kg)} = &+1.245\ [\text{LBM (kg)}]\\ &+0.349\ [\text{Push-up (\# in 1 min)}]\\ &-1.430\end{aligned}$$

Using this equation, a 70 kg individual with 15% body fat (60 kg LBM) and a push-up score of 60 has a predicted BXKNCL of 94 kg. Another individual weighing 54 kg, with 26% body fat (40 kg LBM) and a push-up score of 10 will have a predicted lifting capacity of 52 kg. As with the other predictive equations discussed, this one could be used in a reverse manner in order to derive LBM-push-up combinations meeting critical lift capacities.

Data presented in Table 8 indicate that all of the men and women in this study could lift the minimum shipboard object weight to their knuckle height. Mean shipboard weight could be lifted by 90% of men and 29% of women, while the maximum shipboard weight could be lifted by 31% of men and none of the women.

5. CONCLUSIONS AND RECOMMENDATIONS

Navy PRT scores can be used to predict performance of carry and lift tasks representative of general shipboard work. Run time and LBM (from body circumferences and weight) provide an estimate of performance on a repeated carrying task. LBM also provides a very good indication of muscle strength, in terms of lifting capacity. Combining push-up score with LBM offers some improvement in prediction of lifting capacity. ILM or broad jump scores can be substituted for LBM to provide comparable prediction of lifting capacity. In general, ILM scores do not appear to offer superior prediction over that obtained from PRT scores and other field measures.

If these prediction methods are to be implemented as screening or selection tools, critical lifting and carrying parameters (e.g. load, distance, duration) for Navy jobs must be defined. In addition, further research is needed to 1) cross-validate the results of this study; 2) determine the effects of load, duration, ladder travel and chaining of tasks on carry performance prediction; and 3) determine the effects of object type, lifting height and repeated lifting on lift capacity prediction.

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APPENDIX A

Carry and Lift/Carry Data for Nine Navy Ratings From A Survey of Physically Demanding Tasks (N = 47)*

OBJECT	TASK TYPE	RATE	WEIGHT PER PERSON (kg)	TOTAL CARRY DISTANCE (m)	TOTAL TASK TIME (min)	TOTAL TASK POWER (watt)	REPEAT SEGMENTS PER TASK (#)	CARRY DISTANCE PER SEGMENT (m)	TIME PER SEGMENT (min)	RESTS PER TASK (#)
ANALOG TAPE RECORDER	C	AT-AX	20.4	137.2	15.0	30.5	1	137.2	15.0	1.5
RADAR TRANSMITTER	C	AT-AX	37.5	152.4	15.0	62.2	1	152.4	15.0	1.0
5-GAL CAN NON-SKID	C	BM	27.7	82.3	5.0	74.5	1	82.3	5.0	2.0
5-GAL PAINT BUCKET	LC	BM	31.3	731.5	60.0	62.4	12	61.0	5.0	36.0
RIGGING GEAR PACK	LC	BM	64.7	9.1	2.0	48.3	1	9.1	2.0	3.0
TWO 5-GAL PAINT CANS	C	BM	65.4	152.4	8.0	203.5	1	152.4	8.0	2.0
FUEL PROBE	LC	BM	48.4	11.9	30.0	3.1	1	11.9	30.0	1.0
BOILER SAFETY VALVE	C	BT	34.0	152.4	10.0	84.8	1	152.4	10.0	6.0
NITROGEN BOTTLE	C	BT	31.8	365.8	160.0	11.9	8	45.7	20.0	.0
BARREL DESICANT	LC	BT	33.6	76.2	30.0	13.9	2	38.1	15.0	6.0
LESLIE VALVE	LC	BT	38.6	30.5	15.0	12.8	1	30.5	15.0	2.0
DFT SAFETY VALVE	C	BT	34.0	15.2	20.0	4.2	1	15.2	20.0	
TRANSFORMER	C	EM	45.4	121.9	40.0	22.6	1	121.9	40.0	2.5
VENT FAN MOTOR	C	EM	25.0	121.9	90.0	5.5	1	121.9	90.0	4.0
FIRE FLUSHING PUMP	LC	EM	101.0	9.8	12.0	13.4	8	1.2	1.5	
RED DEVIL BLOWER	C	EM	21.6	45.7	12.5	12.9	1	45.7	12.5	
CABLE OF COPPER WIRE	C	EM	22.7	61.0	20.0	11.3	2	30.5	10.0	
SEA WATER SERVICE VALVE	C	EN	31.3	76.2	5.0	78.0	1	76.2	5.0	4.0
FREON BOTTLE	C	EN	35.4	205.8	12.0	99.2	4	51.4	3.0	.0
FREON BOTTLE	C	EN	37.7	76.2	5.0	93.8	1	76.2	5.0	1.5
NITROGEN BOTTLE	C	EN	31.8	106.7	30.0	18.5	2	53.3	15.0	1.0
BOX OF FLYWHEELS	LC	EN	40.9	9.1	5.0	12.2	1	9.1	5.0	
5-GAL OIL CAN	C	EN	22.7	914.4	37.5	90.4	3	304.8	12.5	.0
FREON BOTTLE	LC	EN	40.9	30.5	20.0	10.2	2	15.2	10.0	.0
5-GAL OIL CAN	C	EN	21.8	152.4	5.0	108.5	1	152.4	5.0	1.0
ACETYLENE BOTTLE	C	HT	39.7	320.0	21.0	98.9	7	45.7	3.0	
ACETYLENE BOTTLE	C	HT	39.7	15.2	5.0	19.8	1	15.2	5.0	.0
LARGE ACETYLENE BOTTLE	C	HT	48.8	18.3	17.5	8.3	1	18.3	17.5	4.0
ACETYLENE BOTTLE	C	HT	39.7	41.2	30.0	8.9	1	41.2	30.0	1.0

APPENDIX A (Continued)

OBJECT	TASK TYPE	RATE	WEIGHT PER PERSON (kg)	TOTAL CARRY DISTANCE (m)	TOTAL TASK TIME (min)	TOTAL TASK POWER (watt)	REPEAT SEGMENTS PER TASK (#)	CARRY DISTANCE PER SEGMENT (m)	TIME PER SEGMENT (min)	RESTS PER TASK (#)
P250 PUMP	C	HT	33.4	15.2	10.0	8.3	1	15.2	10.0	2.0
STEEL PLATE	C	HT	36.3	53.3	60.0	5.3	1	53.3	60.0	2.0
ACETYLENE BOTTLE	C	HT	39.7	9.1	1.5	39.6	1	9.1	1.5	.0
ACETYLENE BOTTLE	C	HT	39.7	152.4	25.0	39.6	5	30.5	5.0	.0
WELDING LEADS	C	HT	54.5	91.4	5.0	162.8	1	91.4	5.0	.0
P250 PUMP	C	HT	33.4	182.9	15.0	66.5	3	61.0	5.0	
BATTERY	C	IC	13.6	91.4	7.5	27.1	1	91.4	7.5	1.5
SYNCHRO AMP	C	IC	20.4	3.4	.5	22.4	1	3.4	.5	.0
MAIN FEED PUMP SHAFT	C	MM	90.8	1.2	.2	90.4	1	1.2	.2	.0
CHOCK	LC	MM	81.7	2.1	5.0	5.7	1	2.1	5.0	2.0
LESLIE REDUCING VALVE	LC	MM	34.0	30.5	15.0	11.3	1	30.5	15.0	
PUMP CASING	LC	MM	35.2	18.3	15.0	7.0	1	18.3	15.0	
PUMP ROTOR	C	MM	27.2	15.2	15.0	4.5	1	15.2	15.0	
TOOL BOX	C	MR	43.1	30.5	3.5	61.4	1	30.5	3.5	.0
BAR STOCK	C	MR	49.9	18.3	.2	746.1	1	18.3	.2	.0
4-JAW CHUCK	C	MR	52.2	1.5	.1	130.0	1	1.5	.1	.0
BAR STOCK	C	MR	86.3	10.7	.3	501.2	1	10.7	.3	.0
CHOCK	LC	MR	32.9	2.4	5.0	2.6	1	2.4	5.0	.0
MEDIAN			36.3	45.7	12.5	22.6	1.0	30.5	7.5	1.0
MEAN			40.8	105.8	19.6	69.3	2.0	54.4	12.4	2.4
S.D.			18.63	173.87	27.43	129.30	2.32	59.55	16.10	5.90
MINIMUM			13.6	1.2	.1	2.6	1	1.2	.1	.0
MAXIMUM			101.0	914.4	160.0	746.1	12	304.8	90.0	36.0

Note: Task Types are Carry (C) and Lift-Carry (LC).
In calculating total task power, vertical distance (i.e., ladder travel) was not included.

* The figures in this appendix were derived through analysis of the data collected by Robertson and NPRDC co-workers during a Navy task evaluation project conducted in 1982. Procedures by which these data were collected are described by Robertson and Trent (1985).

APPENDIX B

Conversion of 2-minute to 1-minute Push-ups

In order to examine the relationship between 1-min and 2-min pushup performance, 29 subjects (23 men and 6 women) were tested in both push-up events. Mean age for the group was 30.7 yrs, with a range of 20 to 41 yrs. Tests were performed 5 to 7 days apart and order of test administration was counterbalanced. The 1-min push-up test was performed as described in the body of this report. The 2-min push-up test was performed according to guidelines given in OPNAVINST 6110.1C. Specifically, participants endeavored to do as many correct push-ups as possible in 2 min, with pausing (rest) allowed only in the strict up-position (arms extended, body straight from head to toe). Any other rest position terminated the test. To begin a push-up, the elbows were bent and the entire body lowered until the top of the upper arms, shoulders, and lower back were aligned and parallel to the deck. To finish the push-up, the elbows were extended until the arms were straight and the body returned to the up-position.

Means (and S.D.s) for 1-min and 2-min push-ups were 45.9 (20.30) and 53.6 (26.11) respectively. Score ranges were 0 to 84 for the 1-min test and 1 to 105 for the 2-min test. In Figure B.1, 1-min scores are plotted against 2-min scores and the line of identity has been drawn for reference.

Stepwise multiple regression analysis was performed with 1-min push-up score as the criterion variable and 2-min push-up score, age and gender as the variables allowed to enter. The only predictor that entered was 2-min push-up ($R = .97$, $S.E. = 5.0$). The regression equation generated was:

$$\text{Predicted 1-min push-up score} = 0.753(\text{2-min push-up score}) + 5.6$$

If desired, 2-min push-up scores from the current Navy PRT could be converted, via this equation, for use in the lifting capacity prediction equations presented in this report.

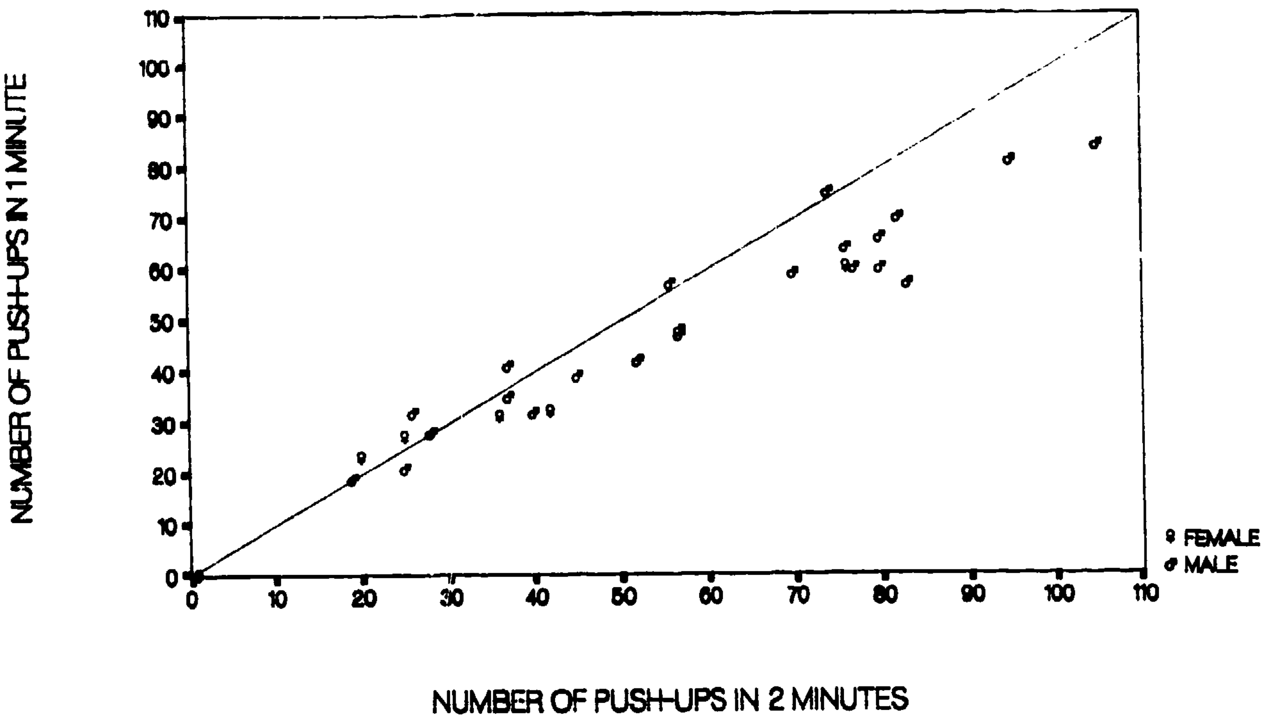

Figure B.1 Comparison of 1-min and 2-min push-up scores. Line of identity is drawn for reference.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS A189 305
None

2a. SECURITY CLASSIFICATION AUTHORITY
N/A

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE
N/A

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
NHRC Report No. 87-26

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Naval Health Research Center

6b. OFFICE SYMBOL *(If applicable)*
Code 70

7a. NAME OF MONITORING ORGANIZATION
Commander, Naval Medical Command

6c. ADDRESS *(City, State, and ZIP Code)*
P.O. Box 85122
San Diego, CA 92138-9174

7b. ADDRESS *(City, State, and ZIP Code)*
Dept of the Navy
Washington, DC 20372

8a. NAME OF FUNDING SPONSORING ORGANIZATION Naval Medical Research & Development Command

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State, and ZIP Code)*
Naval Medical Command National Capital Region
Bethesda, MD 20814-5044

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
63706N	M0096	.02	DN477518

11. TITLE *(Include Security Classification)*
(U) LIFTING AND CARRYING CAPACITIES RELATIVE TO PHYSICAL FITNESS MEASURES

12. PERSONAL AUTHOR(S)
Beckett, Marcie B. and Hodgdon, James A.

13a. TYPE OF REPORT
Final

13b. TIME COVERED
FROM ____ TO ____

14. DATE OF REPORT *(Year, Month, Day)*
1987 October 21

15. PAGE COUNT

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
lifting (U) load carriage (U) physical fitness (U) work capacity (U)

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The purpose of this study was to determine the extent to which performance of simulated general shipboard work can be predicted by measures of physical capacity. Three tasks representative of general shipboard work were developed - an 11-min carry and two maximal box lifting tests. These tasks as well as PRT items (including lean body mass [LBM] from body circumferences and weight) and other field fitness measures were performed by 102 active-duty Naval personnel (6[illegible], 38 women). Incremental Lift Machine (ILM, used by the Army and Air Force [illegible]) sc[illegible] were also obtained. Multiple regression results showed that PRT scores can be used to predict performance of carry and lift tasks representative of general shipboard work. Run time (1.5-mile) and LBM predict carry task performance (R = .72, S.E. = 28.7 watt), while LBM and push-up score predict box lifting capacity (R = .81 to .88, S.E. = 7.6 to 13.2 kg). Substitution of broad jump score for LBM offers a small improvement in task pred[illegible]n. ILM scores offer lift capacity prediction comparable to that obtained fro[illegible] and broad jump scores All of these predictive models

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
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22c. OFFICE SYMBOL
Code 70

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
unclassified

19. cont.

are age- and gender-free. LBM, broad jump and ILM scores are all strong indicators of overall body strength. If these prediction methods are to be implemented as screening or selection tools, critical lifting and carrying task parameters for Navy jobs must be defined. In addition, further research is needed to cross-validate results obtained in this study and to expand prediction application to more specific lifting and carrying tasks.